Effect of Gravity on Surface Tension

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The surface tension of a liquid-fluid pair has been viewed as a thermodynamic property of the system principally dependent on temperature and, to a lesser extent, pressure (refs. 1 and 2). Recent theoretical work (refs. 3 and 4) has introduced the likelihood of an additional body force dependency, in our case gravity, g, which, though perhaps small, may manifest itself at a measurable level. The principal provision enhancing such a measurement would be that the gravity vector be aligned perpendicular to the interface. This is because any variance of surface tension with gravity would be attributable to compressibility effects in the interfacial region, owing directly to an increase/decrease in interfacial thickness; the latter being a dimension of the interface which increases dramatically near the liquid-vapor critical point.

The following is a description of a simple experiment using laser light scattering heterodyne spectroscopy to determine the effects of orientation with respect to earth gravity (g_o) on the surface tension of a liquid-vapor interface. The experimental technique is well established (refs. 5 to 9) and measures the frequency and damping of thermal fluctuations at the surface (thermal ripplons) from which the surface tension is calculated through the dispersion equation.[1] A schematic of the optical path is shown in figure 1. In addition to the potential for increased accuracy, this approach eliminates any gravity dependence on the measurement technique itself, a unique quality when contrasted to other techniques where gravity is essential to the measurement (refs. 11 and 12).

To provide an ability to vary the gravitational field in a terrestrial laboratory, a capillary tube approach was taken in which the tube size was selected for the test fluid which yielded a meniscus that could be inverted (gravity vector opposite in direction to the density gradient), flattened, and stabilized without the heavier fluid falling out. The values as measured in the inverted configuration ($-g_o$) were then compared to measured values of the same fluid in the normal configuration ($+1g_o$, gravity vector in direction of density gradient).

Doubly distilled water (in air) was chosen as the test fluid due to its high surface tension. This permitted the use of a relatively large diameter capillary tube (up to 12.7 mm) and also reduced the ratio of incident beam diameter to characteristic surface length (d/l). The tube diameter selected for this experiment was 9.52 mm.

The tube was made of aluminum and the critical surfaces were machined on an airbearing lathe to a mirror finish. The tube was then fitted to a semi-flexible teflon tube which passed through a volume control fitting and connected the aluminum tube to the fluid reservoir (fig. 2).

The teflon tubing and fittings were cleaned ultrasonically in a mild soap solution and were then rinsed with acetone and/or ethanol and allowed to air dry. The capillary tube was treated separately with an optical cleaning solution to avoid marring the critical surfaces. The assembled components were then flushed with large quantities of distilled water. To monitor possible contamination of the test liquid, Du Noüy ring surface tension measurements were made regularly of the water in the reservoir and the water as drained from the capillary during the flush procedure. In every case these values were 72.5±1.1 dyne/cm. Surface tension values measured of the water left stagnant in the lines for long periods were also consistent at 72.5 dyne/cm.

After extensive flushing the capillary tube was aligned vertically in position for light scattering, either inverted or in the "normal" configuration. Once stabilized, the surface was "flattened" by adjusting the volume of the liquid in the capillary tube. The flatness of the surface was gauged by observing the reflected/scattered light in the far field until it became collumated with a circular symmetric shape. This flat surface condition

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[1]When capillary waves move on a surface both the surface tension and the gravity field provide a restoring force. The latter force enters the theory of the spectroscopic approach through a pressure term of the form $\Delta\rho g\zeta$, where $\Delta\rho$ is the density difference across the interface and ζ is the surface elevation. Thus g appears as a parameter in the dispersion equation ref. (10) under which the assumptions of continuum, linear behavior hold.

could not be maintained for longer than 10 sec due to gradual, though slight, changes in the fluid volume (due to possible thermal expansion, evaporation, and/or pressure leaks) resulting in slight changes in surface curvature. However, for such spectroscopic measurements, only 1 to 5 sec are necessary for the collection of quality data. The data sampling time used for these measurements was 3 sec.

Table I presents the results of the measurements of the surface tension under gravity fields $\pm 1g_o$. The difference is small (0.34 dyne/cm), and when compared to the uncertainties in the measurements it is reasonable to conclude that the difference between the two cases is within the experimental uncertainty. It should be emphasized that both measurements at $\pm 1g_o$ yielded surface tensions which are higher than the commonly accepted values found in the literature. This does not affect the fact that the measurement at $-1g_o$ was slightly higher than the one made at $+1g_o$ since everything in both experiments remained the same except for the orientation. Further tests could be conducted along this line on fluids nearer to critical point conditions where the effect of gravity on the surface tension would be amplified. Such information could prove valuable for future space experimentation where g approaches zero.

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TABLE I.—MEASURED SURFACE TENSION
(USING LIGHT SCATTERING TECHNIQUE)
OF WATER/AIR SYSTEM AT 22C, UNDER
A GRAVITY FIELD OF $\pm 1g_o$. (ALL
MEASUREMENTS PERFORMED
AT ROOM TEMPERATURE 23.5±1C).

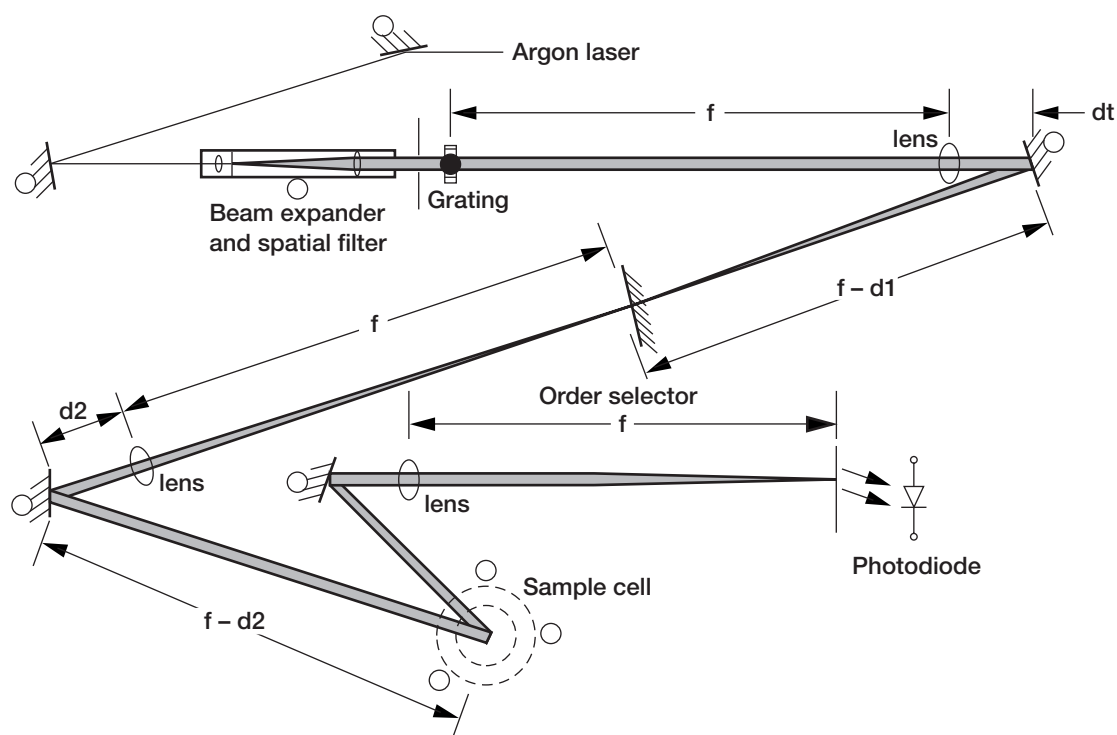| Surface tension, dyne/cm		
Test condition	Measured	Literature
$+1g_o$	73.12±0.41	72.44
$-1g_o$	73.46±0.23	72.44

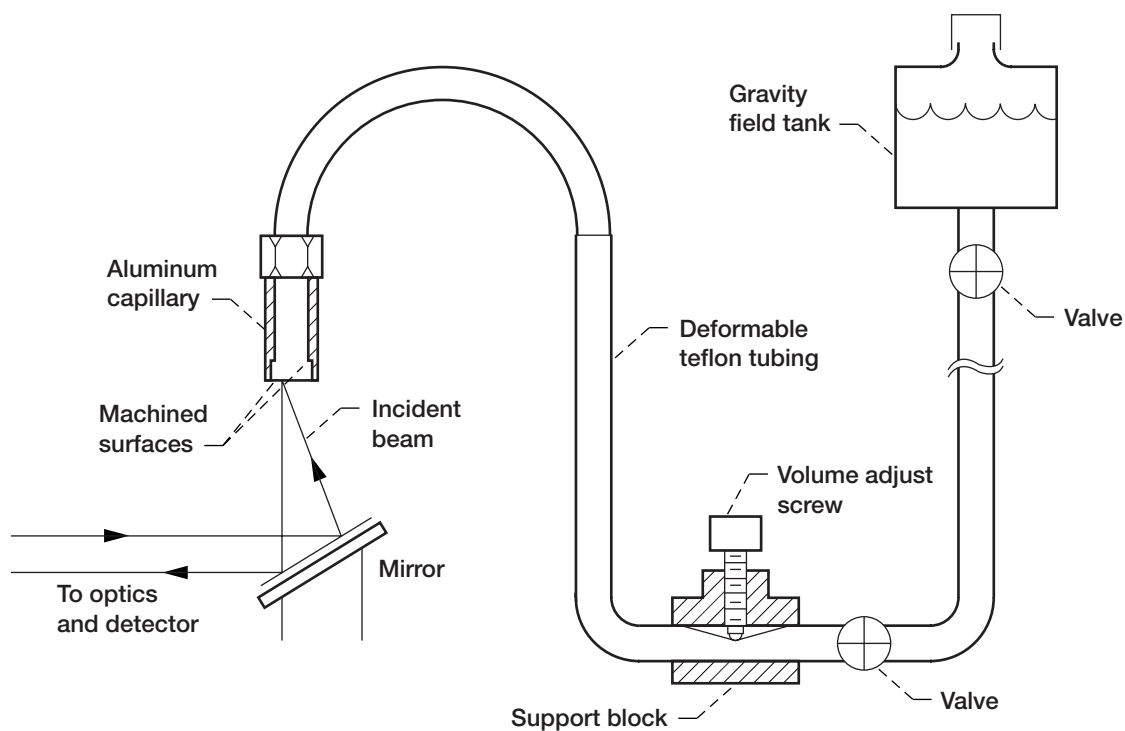Figure 1.—The optical path from the laser to the photodetector.

Figure 2.—Experimental setup for measuring the surface tension of water at gravity fields of + 1g_0 and –1g_0 in a capillary tube. (–1g_0 configuration shown).

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Spectroscopic measurements of liquid-vapor interfaces are made in $\pm 1g_0$ environments to note the effect of gravity on surface tension. A slight increase is detected at $-1g_0$, but is arguably within the uncertainty of the measurement technique. An increased dependence of surface tension on the orientation and magnitude of the gravitational vector is anticipated as the critical point is approached.

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